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Foliar and Nontarget Deposition from Conventional and Reduced-Volume Pesticide Application in Greenhouses†

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Permethrin insecticide was applied to greenhouse-grown chrysanthemums using conventional high-volume (2300 L/ha) and air-assisted, electrostatic, reduced-volume (46 L/ha) spraying systems. The electrostatic reduced-volume application resulted in significantly greater foliar deposition (1.29 vs 0.35 $\mu g/cm^2$). In winter, but not summer, applications, the reduced-volume spraying resulted in longer persistence of deposits. The conventional application resulted in significantly greater contamination of nontarget surfaces of the greenhouse benchtops and aisleways. Mass-balance analyses accounted for 49 and 73% of the permethrin applied by the conventional and electrostatic techniques, respectively. Dislodgeable foliar residue was removed by two techniques, viz., an aqueous surface extraction and a dry mechanical brushing. The ratios of mechanically removed to surfaced-extracted residue were 0.135 and 0.303 for the reduced-volume and conventional treatments, respectively.

INTRODUCTION AND BACKGROUND

Effective control of insect and disease pests is a major concern in production of ornamental plants and cut flowers. Ornamental crops are often extremely susceptible to pests, and economic thresholds to pest damage are extremely low since the crops are marketed exclusively for esthetic appeal. While significant research effort is currently directed toward biological and cultural control strategies for ornamental pests, the application of pesticides remains an essential activity in many production systems. Additionally, pesticide resistance is increasing and ornamentals are typically considered "minor crops" for which the development and registration rate of new pest control compounds is very low in relation to those for large-acreage crops. In addition to requiring stringent pest control, greenhouse ornamental production is labor intensive and the crops are produced in dense, enclosed plantings. The frequent pesticide applications and intensive worker contact with treated foliage and greenhouse work surfaces result in potential exposure of applicators and re-entry workers to pesticide-treated surfaces.

Pesticide application is generally regarded as extremely inefficient, with less than 1% of the applied material eventually reaching and being active against the targeted pest (Pimentel and Levitan, 1986). This inefficiency has motivated research into application techniques to improve pesticide deposition and, in turn, pest control efficacy. In production systems such as ornamentals, where registration of new pesticides is decreasing, application techniques that increase efficacy of existing materials are desirable.

Permethrin is commonly applied for control of leafminers, leafrollers, armyworms, whiteflies, and cabbage loopers in production of ornamentals such as chrysanthemums, roses, and poinsettias. Numerous studies have investigated the effects of application on the behavior of permethrin. The efficacy of permethrin against diamondback moth larvae was found to increase 4–10-fold when spray droplet size was reduced from 274 to 36 μm in diameter (Omar et al., 1991). Similar studies found the persistence (Omar and Matthews, 1991) and rainfastness (Omar and Matthews, 1990), as bioassayed through mortality of *Plutella xylostella* larvae, to also increase as spray droplet size decreased and concentration increased. The relationship between increased efficacy and smaller, more concentrated spray droplets occurs commonly in the literature [e.g., Hislop (1987)].

Giles and Blewett (1991) discussed the motivation for use of electrostatic spraying technology for reduced-volume spraying of small concentrated droplets. Comparison of electrostatic spraying to conventional high-volume application of fungicide to field-grown strawberries determined electrostatic application to achieve significantly greater foliar deposition and longer persistence of pesticide. Sopp et al. (1990) found electrostatic application of a fungal biological control agent (*Verticillium lecanii*) for aphids to achieve superior underleaf deposition and pest control efficacy compared to that of a conventional high-volume sprayer.

While reduced-volume application techniques such as electrostatic spraying, aerosol or "fog" generation, and fumigation may improve pest control efficacy, these systems may also alter the potential worker exposure to pesticides. Lindquist et al. (1987) reported that use of thermal and nonthermal foggers resulted in more variable deposition and higher airborne concentrations of pesticide than conventional high-volume sprays. Pesticide applicator exposure has been investigated (Stamper et al.,

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ment has been shown to effectively mitigate exposure hazards.

Potential exposure of cultural workers who enter and contact pesticide-treated foliage is a significant concern in greenhouse production [e.g., Mestres et al. (1985)]. Potential cultural worker exposure has been closely correlated to the amount of dislodgeable foliar residue (DFR), i.e., residue that can be removed through surface extraction, present on the crop and the characteristics of worker contact with the treated foliage and use of protective clothing. The numerical relationship between DFR (usually expressed as micrograms of pesticide per square centimeter of foliar area) and worker exposure (micrograms of pesticide per hour), viz., the transfer factor (cm^2 foliage/h), has been discussed by Popendorf and Leffingwell (1982), Zweig et al. (1985), and Krieger et al. (1990).

The strong relationship between potential cultural worker exposure and dislodgeable foliar residue implies that application techniques that increase deposition may similarly affect worker exposure. Moreover, application techniques and deposition characteristics can also affect the dissipation rate of the deposit (Pielou et al., 1962; Giles and Blewett, 1991) upon which regulatory re-entry intervals are based. Additionally, most studies of DFR measurement have used the water and surfactant wash or surface extraction technique of Iwata et al. (1977) for residue removal. Such a removal technique is dissimilar to the relatively dry, mechanical transfer process by which cultural worker exposure may occur. This study was motivated by the lack of reported information on the effects of application technique on pesticide deposition, dissipation, nontarget contamination of greenhouse surfaces, and mechanically dislodgeable foliar residue.

OBJECTIVES

The objectives of the study were to contrast the effects of two commercially available application techniques, viz., conventional "wet" spraying and air-assisted, reduced-volume electrostatic spraying on (a) deposition and dissipation of permethrin on greenhouse ornamental plants, (b) nontarget deposition on greenhouse and bench surfaces, (c) mechanical dislodgment of foliar residue, and (d) the total recovery and mass balance of the applied pesticide.

EXPERIMENTAL DESIGN AND TECHNIQUES

Test Crop and Cultural Practices. The experiment was conducted in a 0.65-ha commercial greenhouse located in Sacramento, CA. The house was glass-covered and equipped with steam heating and a forced-ventilation evaporative cooling system. Irrigation water in all test plots was applied through drip emitters positioned in individual plant pots. The ornamental crop used in all tests was "florist-market" chrysanthemums, grown as four plants per 15-cm-diameter plastic pot. During application, typical plant height and leaf area (one side) per pot were 20 cm and 4500 cm^2, respectively. Plants were grown on 1.8 × 12 m wooden benches elevated 0.6 m above ground. Each bench held approximately 180 pots. Benches were separated by 0.6-m-wide walkways extending along the 12-m sides and 2.4-m-wide aisleways extending along the 1.8-m sides.

Application Techniques. Permethrin [3-phenoxybenzyl (±)-*cis,trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate], formulated as Pounce 3.2 EC (supplied as a residue trial grade product by FMC Corp.) was applied at a nominal rate of 3 L/ha, corresponding to 1.15 kg of active ingredient (ai)/ha. The conventional spray application (Figure 1) was made using a commercially available sprayer (FMC Corp.) consisting of a variable-cone nozzle integral within a high-pressure handgun to which liquid was supplied via a 30-m hose from a two-cylinder piston pump operated at a pressure of approximately 2 MPa. The application rate of tank mixture for the conventional spray was 2300 L/ha and was considered typical for "wet" or "full-spray" applications in the greenhouse industry. The reduced-volume application (Figure 2) was made using a commercially available (ESS, Inc.) air-atomizing, induction-charging, electrostatic handgun sprayer based on technology licensed from the University of Georgia (Law, 1978). Characteristics of the electrostatic sprayer were similar to those described by Giles and Blewett (1991). The application rate of tank mixture for the reduced-volume spray was 46 L/ha, representing a 50-fold reduction from the conventional application. Charge-to-mass ratio of the reduced-volume electrostatic spray was approximately ~6 mC/kg. All applications were made by a full-time applicator employed by the cooperating nursery. The application tank mixture for both conventional and reduced-volume spray consisted of water, the permethrin formulation, and Triton B-1956 surfactant (300 ppm by volume). After mixing, tank mixtures were buffered to approximately pH 6.6.

Figure 1. Applicator making conventional wet spray application to chrysanthemums.

Figure 2. Applicator making electrostatic reduced-volume spray application.

Test Design and Execution. The applications were made in summer (June) and winter (December) of 1991. The application technique was similar for each spray system; each bench was sprayed from both sides, resulting in a typical application time of 70 s per bench. The summer trials were conducted on eight benches with four benches treated with each application method. The reduced-volume application was made 7 days after the conventional application. Since the applications were temporally separated, temperature, relative humidity, and insolation were recorded hourly throughout the experiment and are shown in Figure 3. Similarity in environmental conditions during the sampling periods indicated that valid comparisons could be made between treatments. The winter trials were conducted on three benches for each application method. Conventional and reduced-volume applications were separated by 18 h. Since the tests were essentially coincident, no environmental data were recorded. For all applications, the actual

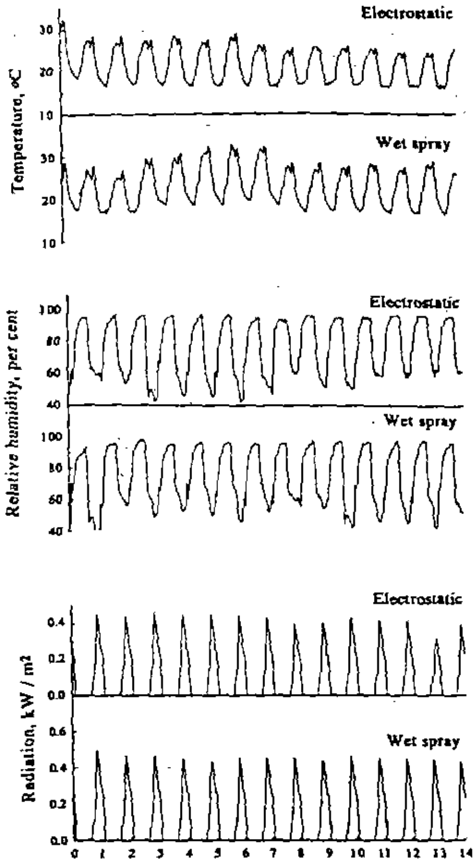

Figure 3. Environmental conditions in greenhouse during residue dissipation sampling from summer application: (top) temperature; (middle) relative humidity; (bottom) insolation.

spray time for each side of each bench was measured and recorded by two observers. The volumetric flow rate from each sprayer was determined by measuring the time required for the applicator to discharge a known volume of spray liquid during actual spraying. The amount of permethrin applied to each test bench was determined from the product of the tank mixture concentration, volumetric flow rate of each sprayer, and the total spray time of each bench.

Deposition Sampling. Spray deposition on the treated foliage, i.e., dislodgeable foliar residue, was determined using techniques similar to those used by Gunther et al. (1971) and Iwata et al. (1977). Forty leaf punches, each 2.52 cm in diameter (400 cm² total surface area), were randomly collected through the foliage on each bench. Sample jars were sealed and refrigerated until extraction. All samples were analyzed within 24 h of collection. Samples were taken 1, 3, 7, and 14 days after each application. Pretreatment samples taken on all benches prior to application detected no permethrin. No additional permethrin was applied to the crop during the sampling periods.

Permethrin was removed from the leaf disk surfaces by using two 20-min washes with a 2% sodium dioctyl sulfosuccinate solution. A liquid/liquid extraction with ethyl acetate was used to extract permethrin from the aqueous solution. Excess water was removed by filtering the extract through anhydrous Na_2SO_4. Aliquots were directly analyzed for permethrin on a Hewlett-Packard 5880A gas chromatograph equipped with a capillary column and an electron capture detector. Cis and trans isomers were separately resolved in each analysis. Approximately equal ratios of each isomer were detected over the study period. All results reported are the sum of cis and trans isomers of permethrin. Recovery for 20 μg of permethrin in the aqueous extract was 98%.

Deposition was s...pl...d on nontarget surfaces using filter paper dosimeters taped to the surfaces. Each dosimeter exposed a 23.76-cm² circ... ...meters were placed on benchtops, on aisle... (Fi...re ...d underneath benches. Dosimeters

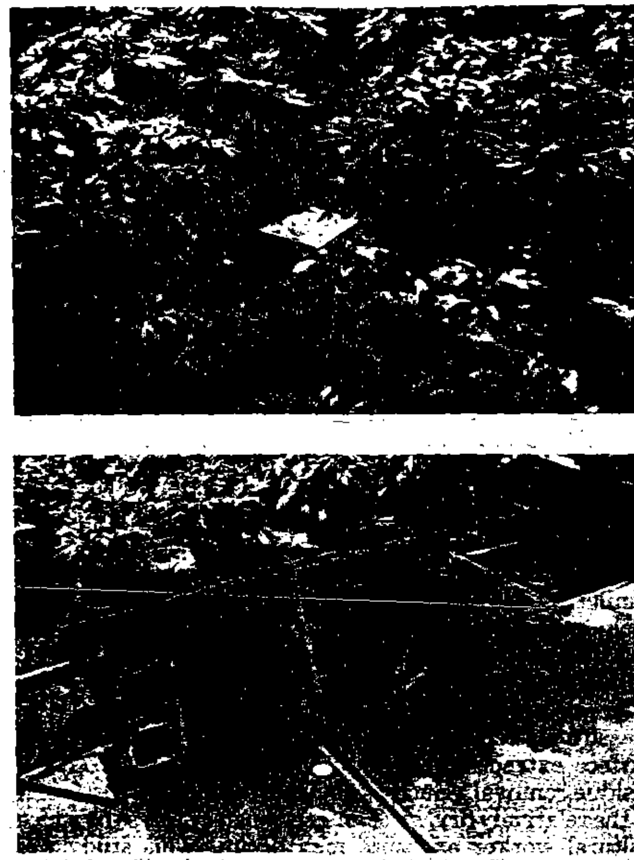

Figure 4. Nontarget deposition collection by filter paper dosimeters on benchtop and aisleway surfaces.

were removed 1 h after application, and the mass of permethrin was quantified by ethyl acetate extraction and gas chromatography as previously discussed.

Twenty entire-leaf samples (approximately 1000 cm² of foliar area) were also collected from each bench 1 day after application. The samples were brushed using a mite brushing machine manufactured by Leedom Engineering, San Jose, CA, and commonly used by entomologists to quantify infestation. The removed solids were collected onto filter paper by a vacuum filtration system underneath the rotating brushes. The filter paper samples were analyzed in a manner identical to that of the nontarget deposition samples. After brushing, leaf areas were determined using an electronic planimeter (Li-Cor Model LI-3000). The brushing operation was a dry, mechanical removal process that represented measurement of dislodgeable foliar residue in a manner more closely simulating actual worker contact with foliage. The technique was conceived within the Worker Health and Safety Branch of CDPR and is continuing to be developed.

Data Reduction. All foliar residue and nontarget deposition values were expressed as micrograms of permethrin per square centimeter of leaf area and surface area, respectively. All values were adjusted to compensate for variation in spray times during application by normalizing all data to a standard application rate of 3.42 g of permethrin per bench. Dislodgeable foliar residue (DFR) data were used to fit a first-order decay equation of the form

$$Q(t) = Q_0 e^{-(t/\tau)} \qquad (1)$$

where $Q(t)$ is the quantity of DFR present on the foliage at time t, Q_0 is the initial deposition or DFR at time zero, and τ is a characteristic time or decay constant. The often-used half-life parameter, $t_{1/2}$, is equal to 0.693τ. Equation 1 was fitted to the observed data by nonlinear least-squares analysis.

RESULTS

Foliar Residue and Dissipation. Estimated parameters and standard errors representing the fitted decay

Table I. Estimated Initial Deposition, Q_0, and Decay Constant, τ, Values (with Standard Errors) from First-Order Decay Models for Each Application and Pooled Data for Each Application Technique

season	application technique	Q_0, μg/cm²	τ, days	r^2
summer	conventional	0.30 (0.03)	11.94 (2.78)	0.66
	reduced-volume	1.45 (0.10)	10.00 (1.71)	0.81
winter	conventional	0.43 (0.03)	11.24 (2.10)	0.81
	reduced-volume	1.10 (0.10)	26.22 (9.73)	0.45
pooled	conventional	0.35 (0.03)	11.59 (2.17)	0.62
	reduced-volume	1.29 (0.08)	13.78 (2.34)	0.65

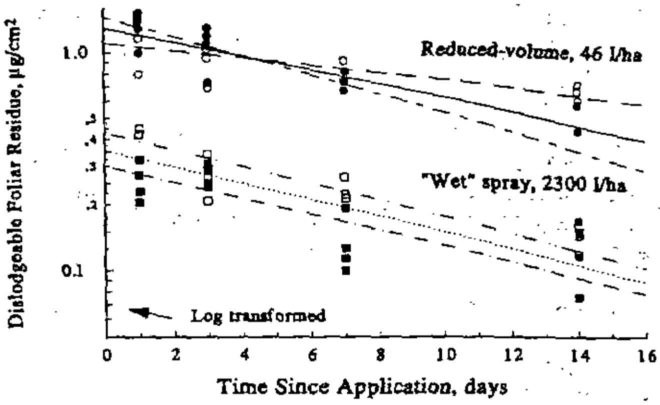

Figure 5. Dissipation of dislodgeable foliar residue from conventional and reduced-volume applications in summer (solid symbols) and winter (hollow symbols).

Table II. Statistical Contrasts of First-Order Dissipation Curves of Foliar Residue from Conventional (C) vs Reduced-Volume (RV) Application[a]

season	H: ($Q_{0C} = Q_{0RV}$)	H: ($\tau_C = \tau_{RV}$)	H: ($Q_{0C} = Q_{0RV}$ and $\tau_C = \tau_{RV}$)
summer	**	ns	**
winter	**	*	**
pooled	**	ns	**

[a] Key: ns denotes failure to reject hypothesis; * denotes rejection at $\alpha < 0.05$; ** denotes rejection at $\alpha < 0.01$.

curves for each spray application are shown in Table I. The curves and observed data are graphically shown in Figure 5. The effects of application technique on deposition and dissipation were rigorously determined by statistical comparison of the fitted decay curves as discussed by Giles and Blewett (1991). Decay curves were tested for coincidence; when coincidence was rejected, further analysis determined whether initial deposition, Q_0, the time constant, τ, or both parameters differed. Results of the hypothesis testing are shown in Table II. Each hypothesis was tested by computing the lack of fit sum of squares produced by imposing the particular hypothesis under test. The mean lack of fit sum of squares was divided by the mean error sum of squares to produce an f statistic for the hypothesis. The hypothesis was rejected if the computed f values exceeded central F values for the appropriate degrees of freedom and α value. Coincidence of decay curves from each application technique was rejected ($\alpha < 0.01$) for summer, winter, and pooled data. Rejection was generally due to the higher initial deposition ($\alpha < 0.01$) from the reduced-volume application. Decay time constants for the application techniques did not significantly differ for the summer and pooled data; for winter data, equality was rejected at $\alpha <$ 0.05.

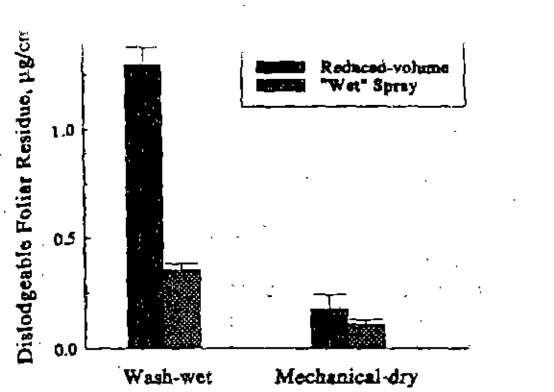

Figure 6. Dislodgeable foliar residue as determined by the technique of Gunther et al. (1971) and mechanically dislodged residue for each application technique. (Standard deviations are shown by bars.)

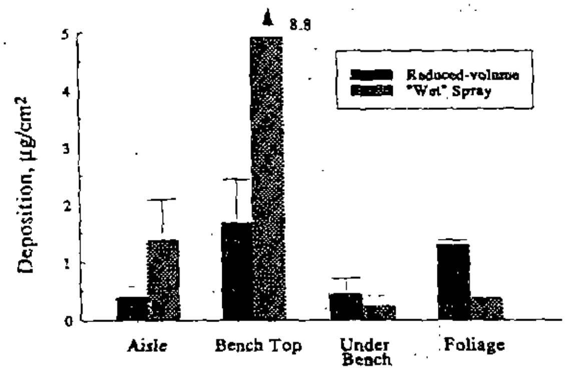

Figure 7. Deposition on all sampled surfaces from each application technique. (Standard deviations are shown by bars.)

Mechanically Dislodged Foliar Residue. The mechanically removed foliar residue for the reduced-volume and conventional applications averaged 0.174 (0.065) and 0.106 (0.021) μg/cm², respectively [standard deviation (SD) in parentheses]. The relative amounts of mechanically dislodged residue and initial deposition from each application technique are shown in Figure 6. The mechanically dislodged residue constituted a much lower portion, 13.5%, of the reduced-volume residue than the conventional application residue, 30.3%. No significant difference was found between the total amount of mechanically dislodgeable residue from each application technique.

Nontarget Deposition. Permethrin deposition on all sampled locations and from both application techniques is shown in Figure 7. The greatest deposition was found on the benchtop surfaces; mean (SD) depositions were 4.91 (3.85) and 1.68 (0.75) μg/cm² for the conventional and reduced-volume applications, respectively. The difference was statistically significant ($\alpha < 0.01$). Deposition on the aisleways averaged 1.38 (0.71) and 0.40 (0.18) μg/cm² for the conventional and reduced-volume applications, respectively. The difference was statistically significant ($\alpha < 0.01$). Underbench deposition averaged 0.24 (0.18) and 0.45 (0.26) μg/cm² for the conventional and reduced-volume applications, respectively. The difference was not statistically significant ($\alpha > 0.10$).

DISCUSSION

Foliar Deposition. Use of reduced-volume, electrostatic application resulted in approximately 3.7 times more foliar deposition (as measured via surface extraction) than use of the conventional wet-spray technique. The relative increase was consistent with results from laboratory mass-transfer studies of electrostatic spraying using similar air-assisted spray-charging technology (Law and Lane, 1981). No significant difference was found in mechanically removed foliar residue from each application technique. The results implied that various application techniques could affect both the amount of initial deposition and the mechanical characteristics of the deposit. The implication was further supported by the apparent interaction between weather and dissipation time of the electrostatically deposited permethrin. Deposition from the conventional sprayer dissipated at essentially the same rate after winter and summer applications; electrostatic spray deposition dissipation was approximately twice as fast in summer as compared with that in winter. It should be noted, however, that concentration of tank mix and application technique were confounded factors in the experimental design. While the design allowed the technologies to be compared in a manner consistent with the intended commercial use, it did preclude any independent, individual evaluation of concentration and application effects.

Nontarget Deposition. Spray deposition on the benchtop surfaces between and underneath the plants was approximately 3 times greater for the conventional application than for the reduced-volume application. Conventional wet-spray application is commonly designed and conducted to intentionally result in spray runoff from the target foliage. In contrast, the reduced-volume application is designed to avoid significant foliar wetting and spray runoff. The results were consistent with the design characteristics of the application techniques. Conventional deposition on the aisleway surfaces was approximately 3.5-fold the reduced-volume deposition. This result was also consistent with the characteristics of the two application techniques. The conventional spray application utilized large droplets with high velocities. Such droplets are more likely to pass through target areas and ultimately deposit on floor surfaces. The smaller, electrically charged droplets from the reduced-volume application are more mobile and, therefore, more likely to move slowly within a foliar canopy until deposition occurs. Application technique did not have a significant effect on deposition underneath the benches. Numerically, the reduced-volume deposition was greater than the conventional deposition. This was possibly due to the greater mobility of the small droplets from the reduced-volume application.

Mass Balance. The study design, with target and nontarget deposition measurement within an enclosed structure, suggested that a mass balance analysis could further illustrate the differences in deposition characteristics from the two application techniques. Moreover, the amount of permethrin applied to each bench was known, and pesticide recovery for the entire experiment could be estimated. The recovered pesticide from the greenhouse benches could be calculated as the sum of the deposition on the individual areas of sampling, viz., foliage (F), benchtop (B) surface, aisleway (A) surfaces, and under-bench (U) surfaces. Arithmetically, the recovered pesticide could be expressed as

$$P_{\text{recovered}} = P_F + P_B + P_A + P_U \qquad (2)$$

$$P_F = (\text{DFR})A_F N \qquad (3)$$

$$P_B = D_B A_B \qquad (4)$$

$$P_A = D_A A_A \qquad (5)$$

$$P_U = D_U A_U \qquad (6)$$

where DFR is the dislodgeable foliar residue (μg/cm^2); A_F, A_B, A_A, and A_U are the areas of plant foliage per pot, benchtop, aisleway, and under-bench areas, respectively (cm^2); N is the number of pots per bench; and D_B, D_A, and D_U are the depositions on benchtop, aisleway, and under-bench surfaces, respectively (μg/cm^2).

Values, with standard deviations or standard errors, for each term in eqs 2–6 are shown in Table III. Foliar deposition values were obtained from the Q_0 estimates from eq 1. Deposition values for the benchtop, aisleway, and under-bench surfaces were directly measured as previously described. The surface area of the aisleway and under-bench areas was measured in the greenhouse; the number of pots per bench was counted. Bench surface area was calculated as the difference between the total benchtop area and the area covered by the 15-cm-diameter plastic pots. Foliar area per pot was measured by removing all leaves from sample pots and measuring the leaf area with an electronic planimeter.

The resulting mass of permethrin for each term (eqs 3–6) and the total recovery (eq 2) are shown in Table IV. The relative recovery, with respect to the applied permethrin per bench (3.42 g) from each source and for each application technique, is shown graphically in Figure 8. The mass-balance analysis could account for 1.68 g, or 49%, of the applied permethrin from the conventional application. The corresponding recovery from the reduced-volume application was 2.49 g, or 73%, of the applied permethrin. While the recovery from the conventional spray application was lower than that from the reduced-volume application (1.68 vs 2.49 g), the uncertainty, or variation, was higher (0.73 vs 0.44 g, or, in relative terms, 43 vs 18%).

Mass-balance and recovery values were not directly measured; rather, the resultant mass values were calculated using a number of independent measurments. In such cases, standard errors of the resultants, or confidence in the values, can only be determined through uncertainty analysis (Kline, 1985; Moffatt, 1985). Standard errors in Table IV were obtained through application of the Kline–McKlintock theorem to eqs 2–6. The partial derivative of each equation was taken with respect to each measurment in Table III. Each partial derivative was evaluated using the observed values in Table III to obtain a sensitivity factor for each measurment. The product of each sensitivity factor and the corresponding uncertainty in each measurment was squared. The terms were summed and the square root was taken to yield the uncertainty in the resultant. The results of the analysis for eq 2, the mass recovery, are shown in Table V as contribution from each measurment to the uncertainty of permethrin recovery. Uncertainty, or variation, in the deposition on the benchtop surface contributed over 95% of the uncertainty in permethrin recovery from the conventional application. Variation in the foliar area per pot contributed over 75% of the uncertainty in permethrin recovery from the reduced-volume application.

Table III. Terms, Numerical Values, and Standard Deviations or Standard Errors Used in Mass Balance (Equations 2–6)

term	units	mean (SD)
DFR[a]	μg/cm²	
conventional		0.35 (0.03)
reduced-volume		1.29 (0.08)
D_B	μg/cm²	
conventional		4.91 (3.85)
reduced-volume		1.68 (0.75)
D_A	μg/cm²	
conventional		1.38 (0.71)
reduced-volume		0.40 (0.18)
D_U	μg/cm²	
conventional		0.24 (0.18)
reduced-volume		0.45 (0.26)
A_F	cm²	8 738 (1656)
A_B	cm²	185 584 (2790)
A_A	cm²	117 057 (609)
A_U	cm²	217 393 (2405)
N		180 (8)

[a] Q_0 values (Table I) are from fit of eq 1; all other values are from direct measurement.

Table IV. Recovery of Permethrin within the Greenhouse[a]

	recovered permethrin, g per bench	
location	conventional	reduced-volume
foliage	0.55 (0.11)	2.03 (0.41)
benchtop	0.91 (0.71)	0.31 (0.14)
aisle	0.16 (0.08)	0.04 (0.02)
under bench	0.05 (0.04)	0.10 (0.06)
total	1.68 (0.73)	2.49 (0.44)

[a] Mean values are shown, and estimated standard errors from Kline–McKlintock uncertainty analysis appear parenthetically.

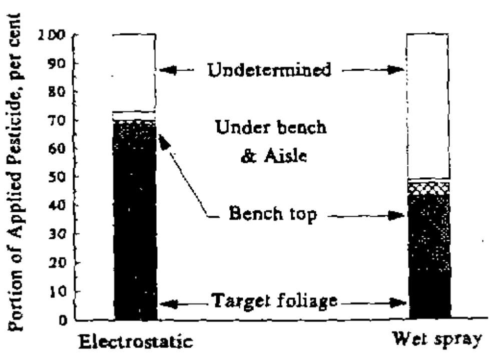

Figure 8. Relative and total recovery of applied permethrin on greenhouse bench areas and target foliage. Calculated uncertainty in each component is shown in Table IV.

CONCLUSIONS

Comparison of conventional and air-assisted, reduced-volume, electrostatic pesticide application techniques found very significant effects on the foliar deposition, residue removal characteristics, location and amount of nontarget deposition, and total mass recovery of permethrin applied within the greenhouse. The reduced-volume electrostatic application resulted in an approximately 3.7-fold increase in foliar deposition. In winter season application, reduced-volume application resulted in significantly longer persistence of foliar residue. Generally, the conventional application resulted in greater deposition on nontarget surface areas, particularly on the benchtop area between and underneath the potted plants. A mass-balance and pesticide recovery analysis determined 59 and 16% of the applied pesticide was deposited on the target foliage by the reduced-volume electrostatic application and the conventional application, respectively.

Tab... Measurement to Final Uncertainty in Total Reclaimed Permethrin

	relative contribution to total uncertainty, %	
source	conventional	reduced-volume
deposition on foliage (DFR)	0.31	8.13
deposition on benchtop	95.94	9.94
deposition on aisle	1.28	0.23
deposition under bench	0.28	1.64
no. of pots per bench	0.11	4.17
area of foliage per pot	2.05	75.88
area of benchtop	0.04	0.01
area of aisle	0.00	0.00
area under bench	0.00	0.00

The results imply that use of the reduced-volume electrostatic application technique could potentially allow 3–4-fold reductions in application rates of pesticide while maintaining foliar deposition equivalent to current conventional spraying. Moreover, use of the electrostatic technology with the reduced rates could potentially result in approximately 10-fold reductions in deposition on nontarget surfaces.

A dry mechanical dislodgment technique was used to remove foliar residue from treated leaves. The technique was investigated as an alternative to the commonly used surface extraction with aqueous surfactant solutions. Unlike the extremely efficient surface extraction, the dry brushing technique may be more sensitive to the mechanical characteristics of the spray deposit and other factors, such as foliar dust, which can affect residue transfer to workers during cultural and harvest operations. The ratios of mechanically removed to surface-extracted foliar residue were 0.135 and 0.303 for the electrostatic reduced-volume and conventional applications, respectively. The results implied that only a fraction of foliar residue that can be removed by aggressive surface extraction in laboratory analysis may actually be available for transfer to workers during commercial operations. Moreover, the fraction of foliar residue available for mechanical transfer was significantly affected by application technique; electrodeposited residue was more difficult to remove.

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